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Review on solar water heater collector and thermal energy performance of circulating pipe

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A B S T R A C T

The effect of thermal conductivity of the absorber plate of a solar collector on the performance of a thermo-siphon solar water heater is found by using the alternative simulation system. The system is assumed to be supplied of hot water at 50 °C and 80 °C whereas both are used in domestic and industrial purposes, respectively. According to the Rand distribution profile 50, 125 and 250 l of hot water are consumed daily. The condition shows that the annual solar fraction of the planning functions and the collector's configuration factors are strongly dependent on the thermal conductivity for its lower values. The less dependence is observed beyond a thermal conductivity of 50 W/m °C for the solar improper fraction and above 100 W/m °C for the configuration factors. In addition, the number of air ducts and total mass flow rate are taken to show that higher collector efficiency is obtained under the suitable designing and operating parameters. Different heat transfer mechanisms, adding natural convection, vapor boiling, cell nucleus boiling and film wise condensation is observed in the thermo-siphon solar water heater with various solar radiations. From this study, it is found that the solar water heater with a siphon system achieves system characteristic efficiency of 18% higher than that of the conventional system by reducing heat loss for the thermo-siphon solar water heater.

Contents

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1. Introduction

Solar water heating (SWH) system comprises several innovations and many mature renewable energy technologies, which have been accepted in most countries for many years. Solar water heating is widely used in most of the countries in all over the world. Nowadays, the world's demand of energy has increased, and it is the natural, safe and costless process to collect hot water by solar radiations. There are many applications of the hot water heated by the solar radiations. Where the solar hot water is used in the domestic purposes, it also is used in industrial applications, e.g. used for electricity generation [1]. Designs suitable for hot climates can be much simpler and cheaper and can be considered an appropriate technology for these places [2].

The storage tank in a 'close-coupled' solar water heating (SWH) system is mounted horizontally above the solar collectors on the roof. Because of the natural rise of hot water through thermosiphon flow into the tank, pumping is not required [3]. The storage tank in a 'pump-circulated' system is mounted on ground or floor below the level of the collectors; a circulating pump is used to move water or heat transfer fluid in between the tank and the collectors SWH system is designed to deliver the optimum amount of hot water for most of the years [4]. However, sometimes there may be an insufficient solar heat gain in winter season to provide sufficient hot water. Where, electric or gas booster in such a case is normally used to heat the water [5].

Energy is an essential factor for the social and economic development of the societies [5]. In future, the present work could be extended to validate the model developed and its economical or environmental impacts on the respective sectors of implementation [6].

2. Solar water heater thermal energy analysis

The Sun produces staggering amounts of energy due to powerful nuclear fusion reaction, and much of that energy is dispersed in space and practically all of it is lost. The Earth is 149,596,000 km far from the Sun and solar flux is relatively small at this distance [7].

The energy intercepted by the Earth over a period of one year is equal to the energy emitted in just 14 ms by the Sun. In other words, solar energy received by the Earth over a period of 1000 years, is equal to the energy produced by the Sun in only 14 s [8]. The solar water simplified layout of the solar collector system with process steam production is shown in Fig. 1 [9]. There are many types of solar water energy analyzing in different papers and articles. One of the boundary systems is the solar collector. A high-temperature heat transfer fluid in liquid phase circulating in a primary circuit gains the heat from solar radiation [10,11]. In the design of a solar energy system using arrays of multiple solar accurately predict dynamic thermal performance for the present system, which uses a panel. The Hottel–Whillier–Bliss model is generally used to evaluate steady state efficiency. The HWB equation did not novel collector array. The theoretical limit of energy gain is 6.5×10^6 BTU for this new array, extending into the nonlinear mode of the HBW equation. Using Bliss equation,

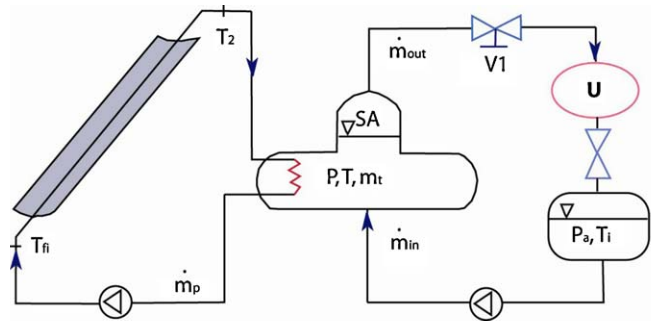

Fig. 1. Schematic diagram of the solar collector system [9,13,16–18].

this equation of collector is modeled and expressed as follows [10,12–14]:

$$n_{coll} = A - BX - CIX^2 \tag{1}$$

where η_{coll} is solar collector thermal efficiency, A, B and C are first, second and third constant for solar collector performance-kW/(m^2 K, m^2 K^2), X is solar collector working condition parameter-m^2 K/kW, I is solar irradiation-kW/m^2.

The X in Eq. (1) can be found by the following equation:

$$X = \frac{[(T_{fo} + T_{fi})/2 - T_a]}{I} \tag{2}$$

where T_{fo}, T_f and T_a are solar collection outlet, inlet and ambient temperatures.

Constants A, B and C can be determined experimentally or calculated considering the optical and heat transfer losses of the collector [15]. In this work, detain the operation are used for a solar tech concentrating parabolic collector.

In Fig. 1, primary and secondary circuits are made together combined. Heat is transmitted from the primary circuit to the secondary circuit. Steam accumulator (SA) stores the water vapor from the secondary circuit. This model is used as a perfectly stirred adiabatic system, by which heat is controlled between two limiting liquid levels with a liquid or vapor separation interface. From the top of the SA, saturated steam is transferred to the thermal user, U at a mass flow rate, m_{out} (m_{out} is mass flow rate exiting from the steam accumulator-kg/s). After leaving the condensate recovery tank of the production plant, water enters to the SA at its bottom with a flow rate of m_{in} at sub cooled condition [10–12,14,19]. When heat demand is increased by the user, the system flow rate is increased by opening the system valve V_1 [9,14,19]. However, the SA is depressurized and flash steam is produced and the level in the steam accumulator falls during this transient period. In order to restraint this level from lowering below the minimum limit, the solar collector has to provide more heat or the condensate flow rate has to be raised. The later, of course, is dependent on weather conditions. If, on the other hand, no heat is extracted from the SA ($m_{out} = 0$), the continuous heat input from the solar collector and the condensate inlet flow rate ($m_{in} \neq 0$) (m_{in} is mass flow rate coming out from the SA, kg/s) leads to a rise in the SA filling level. The model includes a limitation for the SA filling level, as well as for the SA operat-

ing pressures, which is consistent with common specifications for steam production.

The mass balance equation of the SA can be written as [9,16,17]:

$$m_{PT} = \frac{dM}{dt} = m_{out} - m_{in} \quad (3)$$

where m_{PT} is mass flow rate exiting form the system accumulator-kg/s.

Under the assumption of no thermal stratification, the energy balance for the dynamic model of the SA can be written as:

$$\frac{dU}{dt} = \dot{m}_{in}h_{in} - \dot{m}_{out}h_{out} + \dot{Q}_{coll} \quad (4)$$

where h_{in} and h_{out} are enthalpy of $\dot{m}_{in}$ and $\dot{m}_{out}$, $\dot{Q}_{coll}$ is heat rate to heat transfer fluid in the solar collector in kW and can be expressed as follows:

$$\dot{Q}_{coll} = \eta_{coll}\dot{Q}_{sun} = \eta_{coll}ArHb_{tracking} \quad (5)$$

where $\dot{Q}_{sun}$ is heat rate from the sun to the solar collector-kW, η_{coll} is solar collector thermal efficiency, Ar is solar collector aperture area-m^2, $Hb_{tracking}$ is beam irradiance to tracking surface by north–south axis-kW/m^2.

So Eq. (4) can be written as:

$$\frac{dU}{dt} = \dot{Q}_{coll} - \dot{Q}_{PT} - \dot{Q}_{VAP} - \dot{Q}_{SC} \quad (6)$$

where $\dot{Q}_{PT}$, $\dot{Q}_{VAP}$ and $\dot{Q}_{SC}$ are heat rate to compensate for any inlet/outlet flow rate imbalance in steam accumulator-kW, heat rate from saturated liquid to saturated steam condition in steam accumulator-kW and heat rate from sub cooled to saturated liquid condition in steam accumulator-kW.

The amount of energy necessary for changing the thermo-physical conditions of the fluid from incoming sub cooled liquid to saturated steam at steady state, can be expressed by the following equations:

$$\dot{Q}_{SC} = \dot{m}_{in}(h_s - h_{in}) \quad (7)$$

$\dot{Q}_{SC}$ is the heat supply for starting the sub-cooled water thickened coming from the user with a flow rate $\dot{m}_{in}$ up to saturated liquid condition.

$$\dot{Q}_{PT} = (\dot{m}_{out} - \dot{m}_{in})h_s \quad (8)$$

$\dot{Q}_{PT}$ is the energy required to compensate for any inlet or outlet flow imbalance.

$$\dot{Q}_{VAP} = \dot{m}_{out}(h_{out} - h_s) \quad (9)$$

$\dot{Q}_{VAP}$ is the energy necessary for heating the required flow rate $\dot{m}_{out}$ from saturated liquid to saturated steam condition.

3. Thermal performance and program analysis

The solar collector performance model is mainly analogous to the one embodied in program sun, except that it represents only one physical component. Therefore, the program COLTEST, in which it is embodied, carries a single computational module. That computational module contains the same interfaces with environment and other components as the solar collector. In Fig. 2, collector performance is determined by the intensity and angular performance of solar radiation, by ambient temperature and by the temperature of fluid entering it from storage or a conversion by the device [20,21]. Energy output from the collector is described by the rate of heat extraction from it and the temperature at which that heat is removed.

This main program is called COLTEST for the collector test. It is intended to aid in understanding what happens to the energy gathered by a collector throughout a day's operation. Those reasons

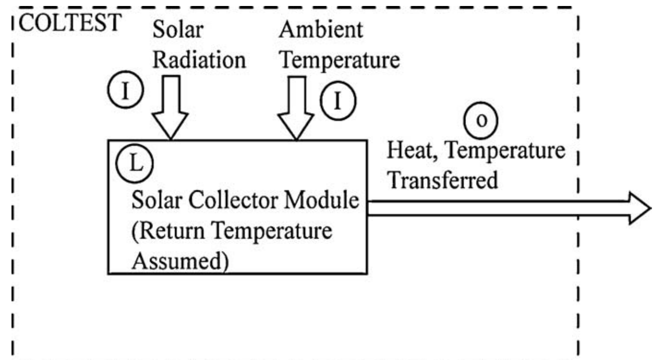

Fig. 2. Computational module and data interfaces [20,21].

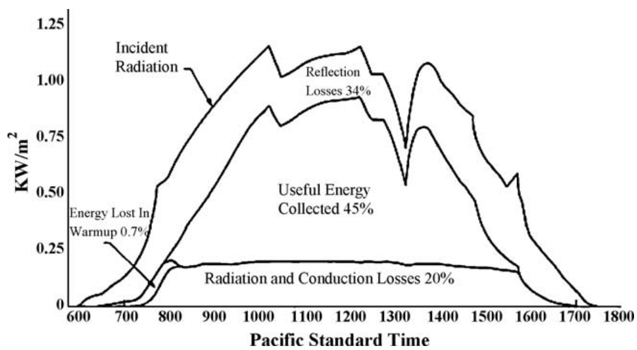

Fig. 3. Performance of collector tilted at 48.5° from horizontal [21,22,25].

it is set up to accept derived inputs and record at closely spaced intervals, simulating performance for one day. Several derived values ware produced tabulating the fact of incoming radiation under the different modes of operation encountered; these are combined in the performance curve shown in Figs. 3 and 4. That analysis is going by assuming the same collector would be kept static until it had attained a minimum temperature [22–24]. The fluid flow rate would be regulated to keep the outlet temperature within a range of 10–15 °C above the minimum temperature. At the end of the day, when the temperature out of the collector dropped below the turn-on level, flow again stopped.

From Fig. 3, it is found that 34% of the energy is lost from the sun radiation, whereas, in Fig. 4, only 9% is reduced. However, the useful energy collected in Fig. 4 is around 57%. The radiation and conduction losses are 20% and 18% shown in Figs. 3 and 4, respectively. Otherwise, the model analysis is the same for solar water heater [23,25,26]. From this, it is very clear that how much energy loss and how much energy saved in a day. This data should be compared for future investment on solar water heater collector.

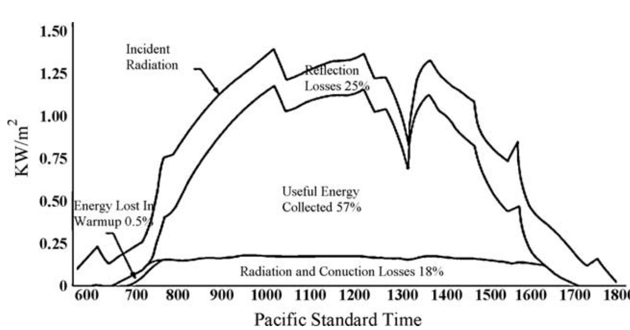

Fig. 4. Performance of collector tilted at 20° from horizontal [21,25].

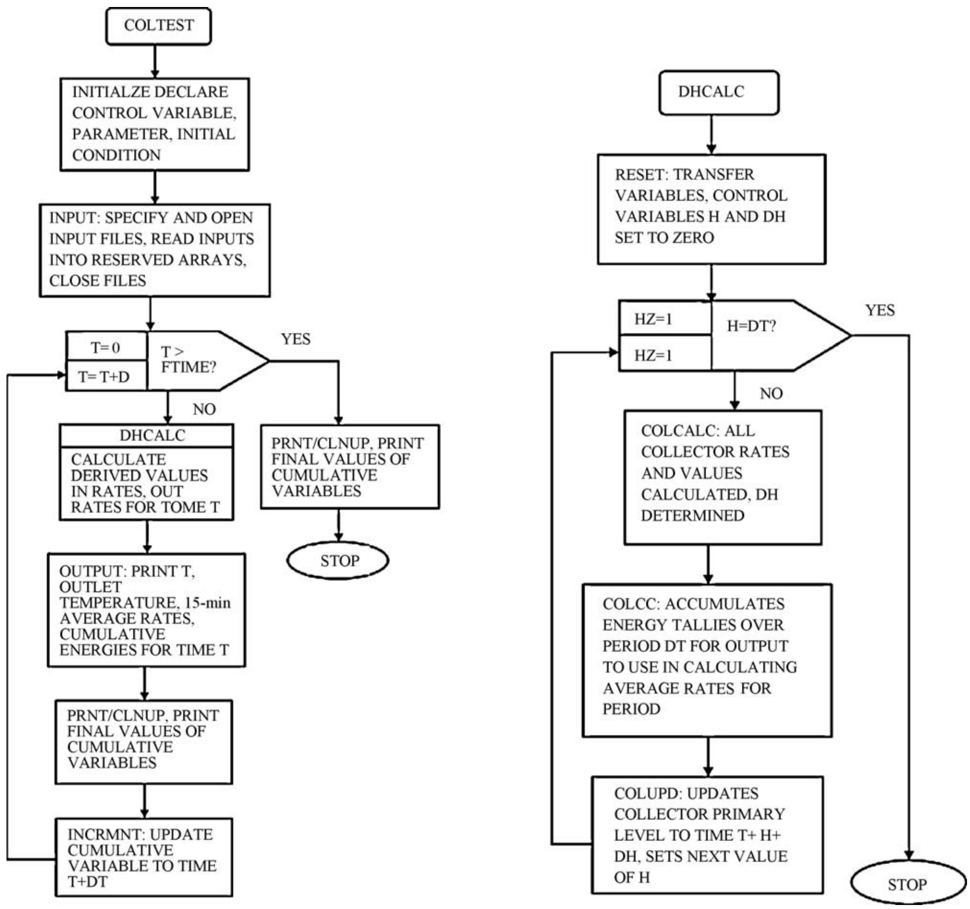

Fig. 5. Level 1 structure, program COLTEST and level 2 structure, program COLTEST [16,21,25].

The COLTEST is exercised in estimating performance characteristics for a conceptual collector design that arose while the Goldstone Energy Project is looking into solar-fired power on demand systems. The flow charts describing the program are shown in Fig. 5. The system under consideration is required delivery of beat at 300 °C or above and is estimated to return fluid to the collector with a 50 °C temperature drop. The hypothetical collector is to have a concentration ratio of 2, involving a single glass cover with 94% transmission to normal radiation. A selectively coated absorber tube of thin copper is postulated; the coating is specified to have 90%absorptive and 5% emissivity [21,22,25].

4. Solar collector plate analysis

It's very common that for active solar-heating systems, solar collectors are the key components. They collect the energy in form of radiations from the sun, convert it into heat and then transfer that heat to a colder fluid (usually water or air). That energy can be utilized in solar space-heating systems, solar pool heaters, and solar water-heating systems [27].

There are a large number of solar collector designs that have been shown as to be functional. These designs are classified in two general types of solar collectors:

- Flat-plate collectors – Overall collector area is the absorbing surface that intercepts the sun's rays.
- Concentrating collectors – smaller absorber is focused with sunlight by big number of mirrors or lenses.

4.1. Flat-plate collectors

At the above simple method for solar collector plate, already gave some method for collector plate. In the application of solar water-heating systems in homes and solar space heating, the flat-plate collectors are the most commonly used solar collector. An insulated metal box with a glass or plastic cover also called the glazing and a dark-colored absorber plate is a typical flat-plate collector, which is shown in Fig. 6. These collectors make hot the liquid or air at temperatures less than 80 °C [1,27].

Flat-plate collectors are used for hydraulic space-heating installations as well as domestic water heating.

4.1.1. Flat plate thermal performance

How to measure the thermal performance and useful energy gain or the collector efficiency of a flat plate? Fig. 7 shows a schematic drawing of the heat flow through a collector. There are

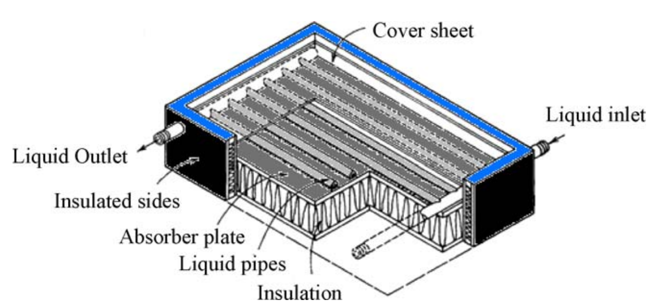

Fig. 6. A typical liquid flat plate collector [10,13,14,19,23,28–33].

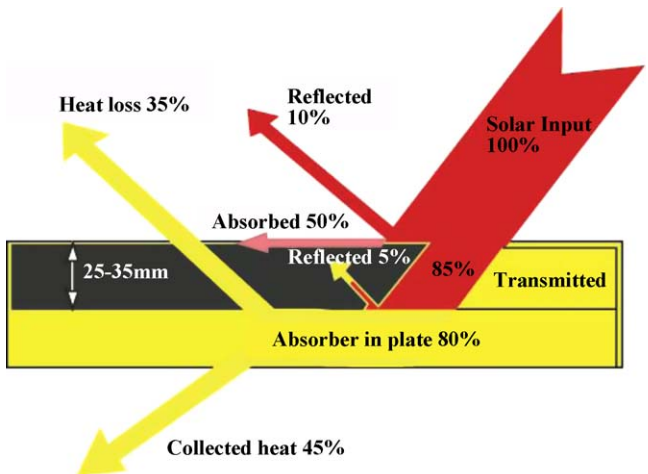

Fig. 7. Heat flow through a flat plate solar collector [1,26,27,33–38].

80% of the sun heat energy is absorbed in the collector plate. The radiant heat reflects and heat loss in the collector surface is around 10–35% shown in Fig. 7 [1,26,27].

It is very essential to define the singular heat flow equations stepwise, in order to find the principal equation of the collector system. There are other some examples for calculating solar energy. Fig. 8 depicts the simple schematic design of a typical solar plate system using a storage tank and flat plate solar collector [6,39,40].

If I is the intensity of solar radiation, in W/m^2, incident on the aperture plane of the solar collector with a collector surface area of A, in m^2, then the amount of solar radiations received by the collector can be expressed by the following equation [27,39–41]:

$$Q_i = IA \tag{10}$$

where Q_i is collector heat input-W, I is intensity of solar radiation-W/m^2, A is collector area.

However, as it shown in Fig. 8, some amount of these radiations is reflected back to atmosphere. Glazing absorbs another component and is transferred through it the absorber plate as short wave radiation. Therefore, the percentage of the solar radiations, which penetrate the transparent cover of the collector and the percentage of radiations being absorbed, is indicated by the conversion factor. Basically, it is the product of the rate of transmission of the cover

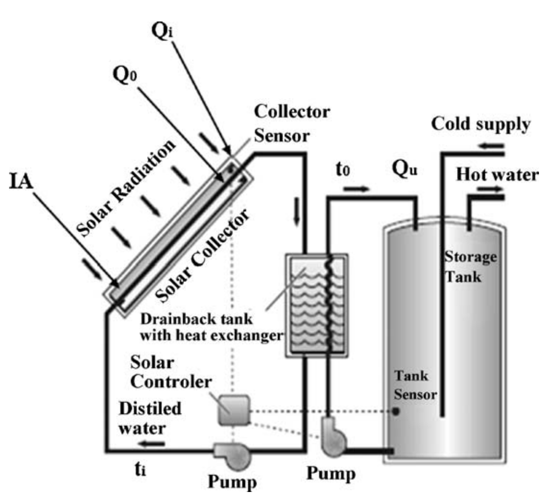

Fig. 8. Typical solar energy collection system [39,40].

and the absorption rate of the absorber and can be expressed as follows:

$$Q_i = I(\tau\alpha)A \tag{11}$$

where $\tau\alpha$ is transmission and absorption coefficient of glazing and plate.

As the collector absorbs heat, its temperature is becoming higher than that of the surrounding and thermal energy is transmitted to the atmosphere through convection and radiation. The rate of heat loss, Q_o is dependent on the overall heat transfer coefficient U_L of collector and its temperature. The rate of heat loss, Q_o, can be expressed by the following equation:

$$Q_o = U_L A(T_c - T_a) \tag{12}$$

where Q_o is heat loss W, U_L is collector overall heat loss coefficient W/m^2, T_c is collector average temperature °C and T_a is ambient temperature °C.

Thus, the rate of useful energy extracted by the collector Q_u, expressed as a rate of extraction under steady state conditions, is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings [27,31]. This is expressed as follows [9,39,40,42]:

$$Q_u = Q_i - Q_o = I\tau\alpha \cdot A - U_L A(T_c - T_a) \tag{13}$$

where Q_u is useful energy gain-W.

The rate of heat extraction from the collector can be measured by means of the amount of heat carried away by the fluid passing through it and can be expressed as follows:

$$Q_u = mc_p(T_o - T_i) \tag{14}$$

where m is the mass flow rate of fluid through the collector-kg/s.

Eq. (13) proves to be somewhere inappropriate because of the difficulty in defining the collector average temperature. It is easy to define a quantity, which relates to the actual useful energy gain of a collector surface that is at the fluid inlet temperature. This quantity is known as the collector heat removal factor, F_R and is shown by Eq. (15) [9,39,40,43]. Actually, the collector heat removal factors are three types.

$$F_R = \frac{mC_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)]} \tag{15}$$

When the whole collector is at the inlet fluid temperature the maximum possible useful energy gain in a solar collector is achieved. The product of the collector heat removal factor F_R and the maximum possible useful energy gain gives the actual useful energy gain Q_u, allowing the rewriting of Eq. (13). This equation is found by Hottel–Whillier–Blisseuation [12,27,39,44,45].

$$Q_u = A_c\,\Delta t F_R[I_T(\tau\alpha)_n - U_L(T_i - T_a)]$$

The collector efficiency η is the measure of a flat plate collector performance, which is defined as the ratio of the useful energy gain Q_u, to the incident solar energy over a particular time period:

$$\eta = \frac{\int Q_u\ dt}{A\int I\,dt} \tag{16}$$

And the thermal efficiency of the collector is:

$$\eta = \frac{Q_u}{AI} \tag{17}$$

$$\eta = \frac{F_R A[I\tau\alpha - U_L(T_i - T_a)]}{AI}a \tag{18}$$

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \tag{19}$$

The collector efficient η is plotted against $(T_i - T_a)/I$. The slop of this time $(-F_R U_L)$ represents the rate of heat loss from the collector. As,

for example, collectors without cover sheets will have more slope than those with cover sheets.

This is an example of an experimental work [27,46–48] for some days. The energy required to raise the temperature of 1 l of water by 1 °C is 4.19 kJ. If the capacity of the system is *C* liter and temperature of water to be raised by *T* °C, the energy required should be,

$$E = (4.187 \times C \times T)\,\mathrm{kJ} \tag{20}$$

[This is the energy required equation and 1 calorie of heat is equivalent to 4.187 J].

The assumptions that considered are:

(a) Mass of water m to be heated is 100 kg.
(b) Initial temperature of water is 20 °C, which was the lowest temperature on December 10th.
(c) Water is to be heated up to 60 °C.
(d) Specific heat of the water is 4.19 kJ.

From the equation:

$$E = \{4.19 \times 100 \times (60\,^\circ\mathrm{C} - 20\,^\circ\mathrm{C})5\,\mathrm{s\,kJ} = 16760\,\mathrm{kJ}$$

The assumptions made for the determination collector absorber area are:

(1) Heat required per day = 16,760 kJ.
(2) Energy incident on the inclined surface of collector is = (619 × 9 × 60 × 60) kJ/m^2/day = 20,055 kJ/m^2/day.
(3) Overall efficiency of collector is taken as 40% by considering the lower limit.
(4) Collector absorber area required is calculated as, collector area = (energy required/energy available × efficiency) m^2 = (16760/20055 × 0.4) m^2 = 0.3 m^2.
(5) Slope of collector (β) angle of inclination δ is calculated from equation

$$\delta = 23.45\ \sin[0.9863(284 + n)] \tag{21}$$

For January, n = 20

$$\delta = -20.34$$

Slope of collector β is calculated by formula $\beta = (Q - \delta)$ where Q = latitude at test site, =21°.6N

$$\beta = [21.6 - (-20.34)] = 41.94^\circ\,(\text{i.e.},\ 42^\circ)$$

As the value β of is +42°, collector should be south facing at an angle of 42°.

(6) Solar water heater efficiency from Eqs. (17), (18) or (19) [12].

4.2. Concentrating collectors

Direct beam (ray) solar radiation data are presented for four concentrators: one axis tracking parabolic troughs with a horizontal east–west axis, one-axis tracking parabolic troughs with the axis oriented north–south and tilted from the horizontal at an angle equal to the latitude and two axis tracking concentrator systems. Solar direct beam radiations come straight and are measured with the instruments having a field of view of 5.7°. Only the sun's disk and a small portion of the sky surrounding the sun are visual by these instruments [34,49,50].

There are many types of concentrating collectors. The most popular types are the parabolic one. Fig. 9(A) shows a linear concentrating or parabolic though a collector. It collects energy at a small absorber tube by reflecting direct solar radiation with large curved mirrors into it which carries flowing heat transfer liquid. The absorber tube may be evacuated, which is encased in a glass or metal tube. The sun is tracked and only direct radiations are collected by this type of collector [24,50,51].

Fig. 9(B) shows a linear trough august in jean Fresnel collector. However, in this design, a curved lens is used to focus incoming rays on to a small absorber plate or tube through which the heat transfer liquid is circulated. These types of collector also require a tracking mechanism and can collect only direct radiation [8,35,50,52].

Fig. 9(C) shows a compound parabolic mirror collector. The design of the mirror allows the collector to focus and collect both direct and diffused radiations without tracking the sun ray. The only necessary adjustment is periodic changes in the tilt angle. Only a portion of the mirror at a time intercepts direct radiation; thus collector does not achieve as much solar energy as a focusing collector does, which tracks the sun. However, it is, not too much expensive for installation and maintenance. The absorber tube is encased with an evacuated tube for heat losses reduction. There are many types of collectors with good efficiencies, which produce high temperatures [3,20,36,53]. On the other hand, the high cost of installing and maintaining tracking collectors restricts their use to solar cooling and industrial applications where extremely high fluid temperatures are required. In addition, concentrating collectors must be used only in that location where clear sky direct radiation is abundant [28,32,46,54].

In general, the classification of the solar water heater is of two types. From U.S. department of Energy efficiency and Renewable Energy, they said that most solar water heaters required a well-insulated storage tank. Solar storage tanks have an additional outlet and inlet connection to and from the collector. In two-tank systems, the solar preheats water before it enters the conventional water heater. In one tank systems, the backup heater is combined with the solar storage in one tank [12,55,56].

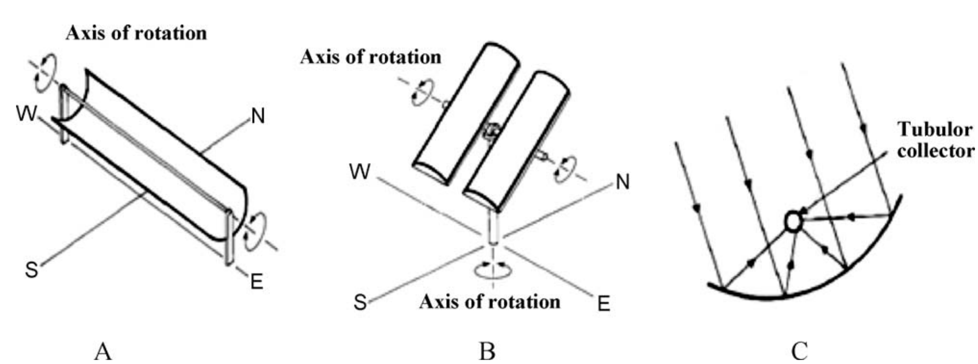

Fig. 9. One-axis tracking parabolic trough with axis oriented east–west and one-axis tracking parabolic trough with axis oriented east–west [1,14,50].

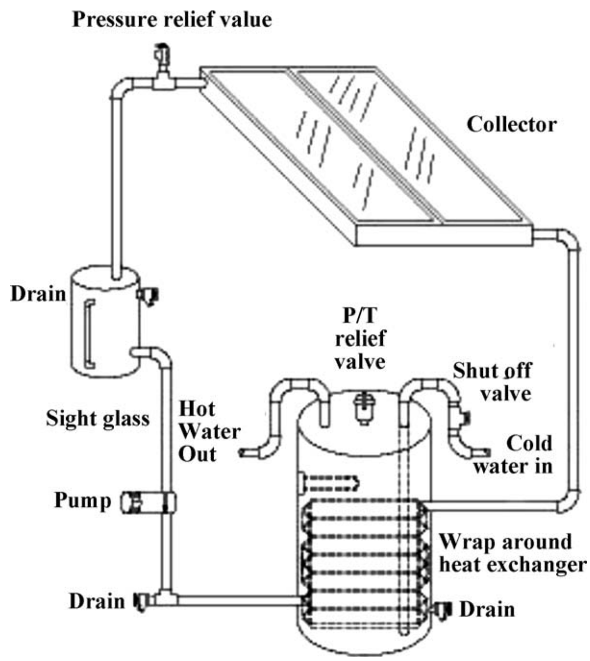

Fig. 10. Integral collector storage system [40,57].

5. Types of solar collector

Generally three types of solar collectors are used for residential applications that are described below.

5.1. Flat plate collector

Glazed flat plate collectors are equipped with insulation and weather proofed boxes that contain a dark absorber plate under one or plastic (polymer) or more glass covers. Unglazed flat plate collectors heaters having a dark absorber plate made of metal or polymer, without a cover or enclosure are typically used for solar pool [9,28,57].

5.2. Integral collector storage systems

Furthermore, ICS (integral collector storage) or batch systems feature one or more black tanks or tubes in an insulated, glazed box. The water then continues on the conventional backup water heater, providing a reliable source of hot water. They should be installed only in the mild freeze climates because the outdoor pipes could freeze in severe the cold weather. Fig. 10 shows an integral solar water heater [40,57].

5.3. Evacuated tube solar collectors

They feature parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin's coating absorbs solar energy but inhibits radioactive heat loss. These collectors are used more frequently for U.S. commercial application. In Fig. 11, the evacuated tube solar water heater has been shown which a very popular solar collector is in present time. This is a very effective way to collect hot water from the sun, but it is also expensive to set up [57,58].

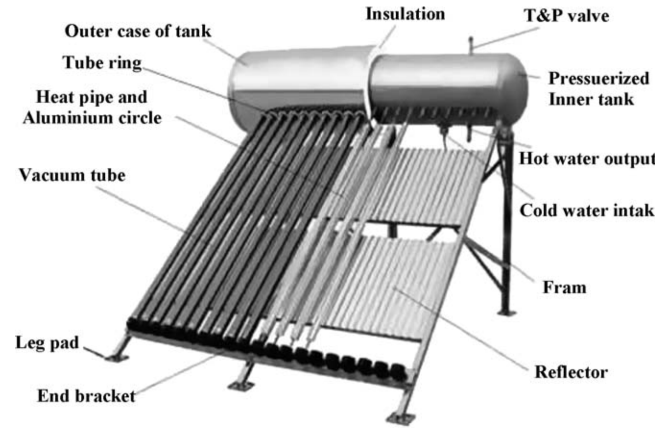

Fig. 11. Evacuated tube solar water heater collectors [57,58].

6. Active solar water heating system

There are two types of active solar water heating systems. These are direct circulation system and indirect circulation system. These are discussed in the following sections.

6.1. Direct circulation system

Pumps are used to circulate household water through the collectors and supply to the house. They work well in climate where it rarely freezes. Fig. 10 shows how direct circulation system works [38,40,50].

6.2. Indirect circulation system

Pumps circulate a nonfreezing, heat transfer fluid through the collectors and a heat exchanger. This heats the water then flow into the home. They are popular in climates prone to freezing temperatures. Fig. 12 shows the indirect circulation system of a solar water heater. This is a very simple system for heating water. The pump only circulates water between a heat absorber and a water cylinder, and then the hot water flows outside the storage tank [55,57].

7. Overall thermal photovoltaic performance of solar water heater

The photovoltaic thermal system considered by Huang et al. [59] has been used for energy analysis. It consists of an insulated cylindrical storage water heater of capacity 45 kg and photovoltaic system 0.516 m^2. There is a connection in between storage tank and PV module through insulated pipes. Water is circulated in between the storage tank and the photovoltaic or thermal collector by using a water pump, which consumes 3 W of electrical energy. The hot water from storage can be withdrawn at the constant flow rate and constant collection temperatures. The circuit diagram of an integrated photovoltaic thermal system with hot water withdrawal at

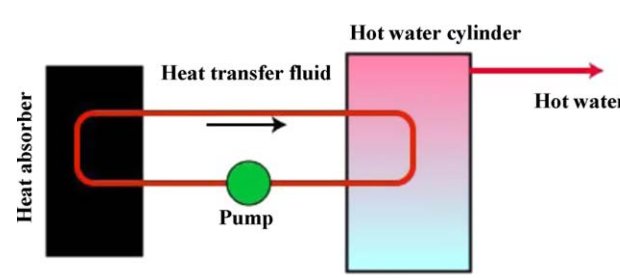

Fig. 12. Indirect circulation systems [55,57].

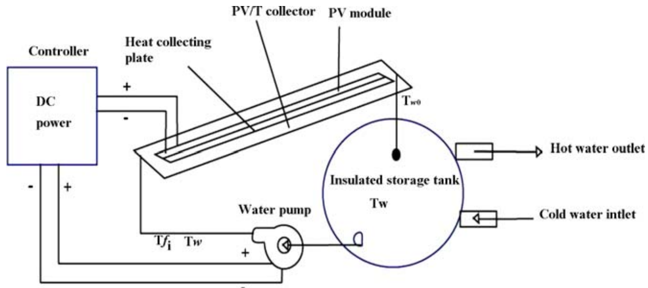

Fig. 13. Schematic diagram of an integrated PV/T system [59,60].

constant flow rate has been shown in Fig. 13 [60]. In the present study, the electrical efficiency (η_c) dependent on temperature of PV module has been considered for the present analysis, and its expression is given by [61]:

$$\eta = \eta_r[1 - 0.0045(T_c - T_r)] \quad (22)$$

where T_c is the average temperature of cell, T_r is the reference temperature, η_r is reference efficiency of the module. At temperature of 25 °C and solar intensity at 1000 W/m^2, the present value of reference efficiency is 12%. If the packing factor is also included then the electrical efficiency of the PV module can be defined as:

(23)PF = (Number of solar cell × area of one solar cell)/Area of PV module

8. Thermal analysis in two dimensions

This is the approximation towards the numerical simulation of the collector and a simplified two-dimensional thermal model coupled with a one dimensional model in the fluid. The computational domain is being a cross section of the collector corresponding to one duct, which is shown in Fig. 14 [62,63].

The stationary heat equation is then numerically solved together with boundary condition accounting for the energy losses through the surrounding area. On the plate, the absorbed solar irradiance is taken into account together with the heat losses through radiation and convection.

On the duct area, a convective boundary condition is considered using the mean fluid temperature which is computed solving the one dimensional convective heat equation in the fluid with the useful heat transferred from the duct to the fluid as a source. This model was implemented and solved by a finite element method in Comsol Multiphysics [64]. For stationary conditions, Tables 1 and 2 show the data for the numerical simulation and the result for the main thermal parameters that characterize the behavior of the collector, respectively. In Fig. 15, the computed collector efficiency line is presented.

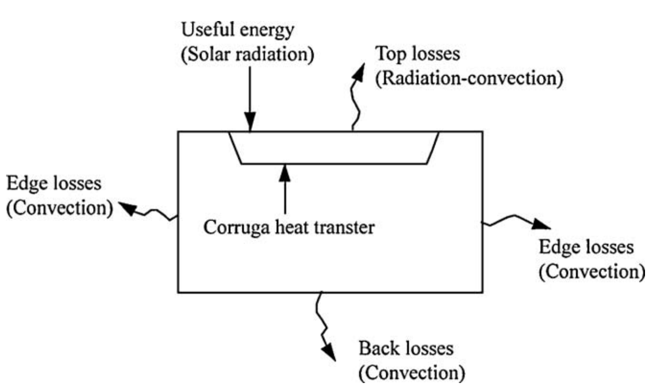

Fig. 14. Sketch of energy losses in the collector plate [62].

Table 1
Data for the numerical simulations [64].

Horizontal plane	Single glass
Collector tilt angle	0°
Ambient temperature	20 °C
Fluid temperature	20 °C
Flow rate	0.01 kg/s
Irradiance	1000 W/m^2

Table 2
Result of the two dimensional simulations [64,65].

Data found the collector	Results
Efficiency	84.5%
Slope	−3.021
Maximum surface temperature	31.7
Fluid temperature rise	18.7
Overall heat loss coefficient	3.1 W/m^2 K
Collector heat removal factor	0.96

This result of methodology was extended to the transient case coupling with:

(a) The two dimensional transient equations in the collector cross section.
(b) The one dimensional convective heat equation modeling the temperature in the fluid.
(c) The differential equation governing the temperature rise on an unstratified tank.

Moreover, for the transient model, the irradiance in Fig. 15 and ambient temperature in Fig. 16 are given throughout the day. The volume of the unstratified tank is 0.3 m^3.

It is dependent on the operation conditions that the solar water heating systems can be either active or passive. Passive system uses no any pump, whereas an active system uses an electric pump to circulate the heat transfer fluid. These could further classify fluid into direct and indirect types. A direct solar water heating system circulates domestic water through collectors and is not suitable for very low climatic temperatures; indirect type uses a heat transfer fluid. These active or passive modes of energy transport can be used in any of the flat plates, evacuated or concentrating type of collector [67].

The thermal performance of a solar water heater collector efficiency curve is an important physical property of a solar collector. The efficiency of a collector is defined as the ratio of the amount of energy transferred from the collector to the heat transfer medium to the incident radiant energy on the collector. In Fig. 17, a sur-

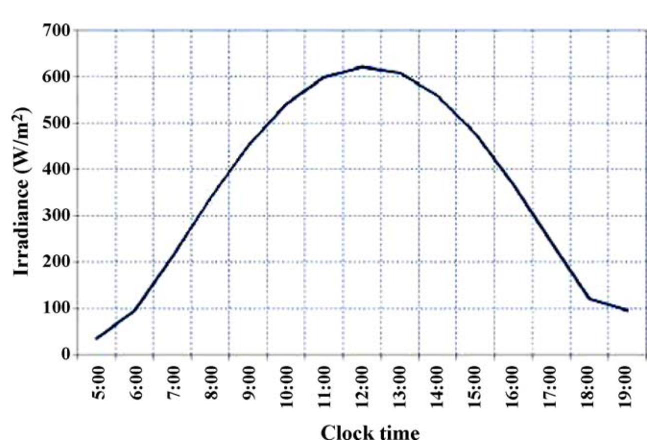

Fig. 15. Daily irradiance [62,66].

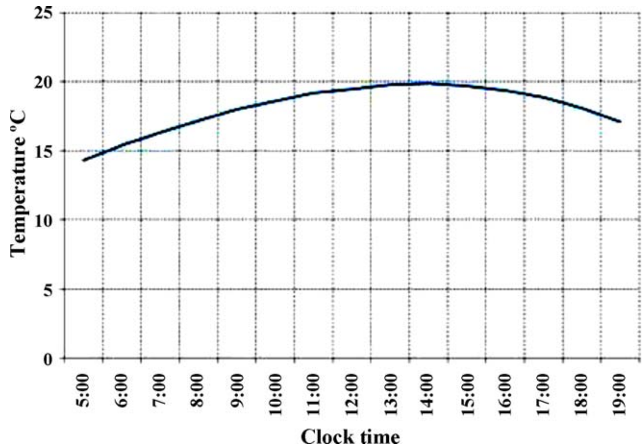

Fig. 16. Average daytime temperatures [62,66].

vey of comparison among the different types of solar collectors [68] indicates that particularly, the radiation losses dominate the efficiency due to collector's area. There are more losses in concentrating type of collector. A certain collector's efficiency is dependent on its location, temperature, wind speed, and so on but not a fixed value [62,68].

From Fig. 17, it is found that different types of collector perform in different ways. The main effect is that the efficiency in all collectors is same. In the graph, the performance of the evacuated tube is higher than the other collector. Nowadays many countries use flat plate water heater. This collector has become easier to install at houses and in the industries.

9. Solar water heat energy produced

This is the survey of the solar water heater thermal condition. It is an example of using the solar heating system in Bozeman USA [54].

9.1. Collector inlet temperature

Basically, this is the temperature that about the strong tank will average during the period of collection. The recommendation temperature is 30 °C (86 °F) for radiant heating perhaps a bit low as an average tank temperature. They used 35 °C (95 °F) for their system. As this temperature lowers the efficiency of the collector will increase, therefore, systems should be designed in such a way this temperature should be kept as low as possible [54,69–71].

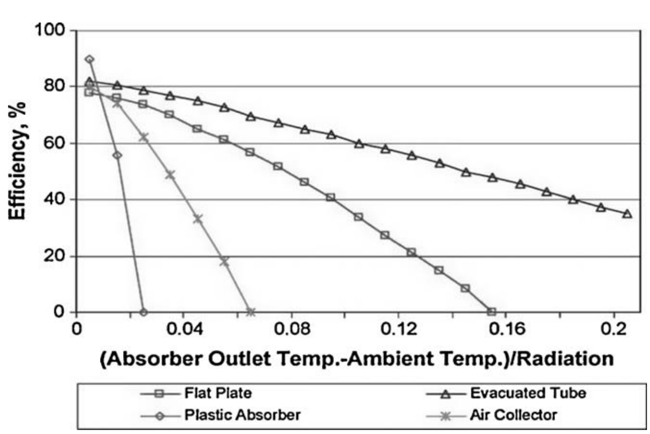

Fig. 17. Collector efficiency curves for various types of collectors [1,9,12,16,27,67].

9.2. Collector outlet temperature

The outlet temperature used 40 °C. The collector outlet temperature should be about 5 °C above the collector inlet temperature. Then collector flow rate should be increased if it's actually more [18,48,54].

9.3. Collector tilt

Collector can tilt 70°. Collector is tilted up from horizontal with this angle (0° is in horizontal and 90° is in vertical). Positive angle for collector tilt is picked if it is in the northern hemisphere. For solar space heating systems, steep tilt angles are the best.

In Fig. 18, the result for each day shows the system output in KWH per sq meter of collector area. The output covers the period of the day of the year, and the output is shown for the beat year, worst and median year. So for example, let's go to calculate the collector output and the fuel and CO_2 saving for the on March.

9.4. Solar heat energy produced

From Fig. 18, it is found, for March from 60 to 90; the median energy output appears to be about 1.6 KHW per sq meter of collector. So for the 31 days of March, the heat output in SI unit can be expressed [54,72–74]:

$$(1.6\,\text{KWH/day-m}^2)(22.3\,\text{m}^2)(31\,\text{days}) = (1106.08)\,1106\,\text{KWH for the month.}$$

To get the output in US units, make use of the fact that 1 KWH equals 3412 BTU and 1 m^2 equals 10.76 sq ft. So in 1.6 KWH/m^2 is equivalent to (1.6 KWH/m^2) × (3412 BTU/KWH) (1 m^2/10.76 sqft) = 507 BTU/sqft per day. The monthly total energy is then:

$$(507\,\text{BTU/sqft-day})(240\,\text{sqft})(31\,\text{days}) = 3.77\,\text{million BUT for the month.}$$

9.5. Fuel savings in these presses

Used propane (colorless gas found in natural gas and petroleum) fuel and the efficient 90% is a furnace. Just for as an estimate and an overall efficiency of its heating system with duct losses and so on. Maybe 70 or 80%, they will use 75%. So the propane saving is [54]:

$$(3,770,000\,\text{BTU})/((92,000\,\text{BTU/gal})(0.75\text{efic}))$$
$$= 54.7\,\text{gallons of propane saved for March.}$$

If the system heat electrical at 95% efficiency, then the saving would be:

$$(1106\,\text{KWH})/(0.95\text{efic}) = 1164\,\text{KWH per month}$$

This is the estimating for saving our fuel, money and electricity. It is an example for solar water heater energy saving above the requirements. Energy storage and thermal performance are the main effect in this paper for using the solar water heater collector.

10. Energy storage and auxiliary heat by solar water heater

The effective sunshine occurs only about 5–6 h per day and since heating and hot water loads occur up to 24 h a day. Some type of energy storage system is needed when using the solar energy. Practical experiences in the industry as well as computer simulations and experiments have resulted in rules of thumb for storage sizing. These guidelines provide storage sizes for which the optimized and relatively insensitive to changes within the range indicated [75].

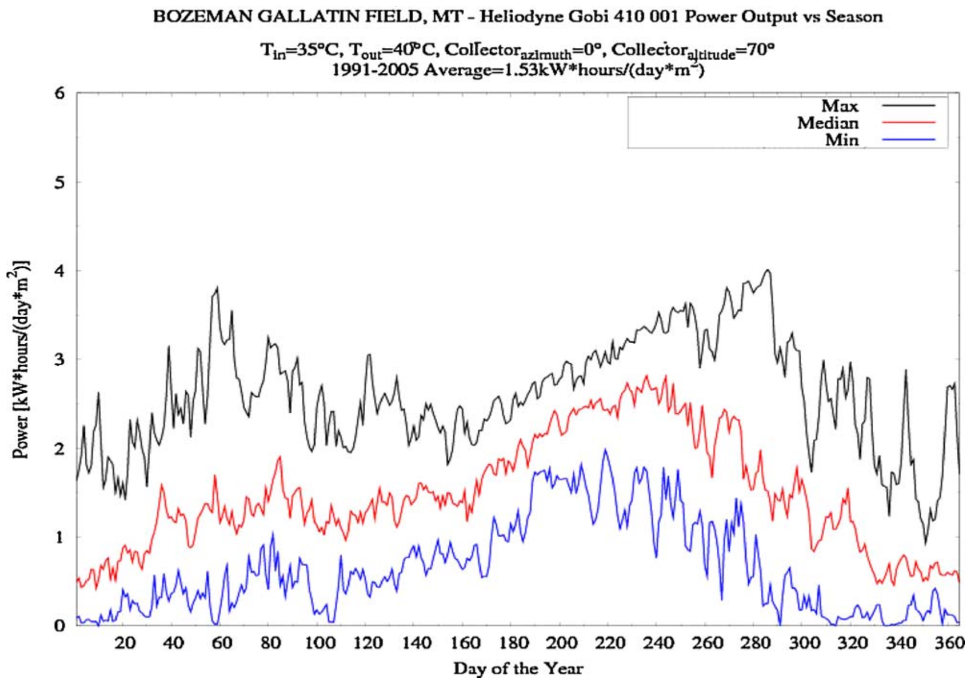

Fig. 18. Output simulation example for heat energy [54].

10.1. The renewable-energy and energy-efficient technologies screen (RETs) program

This is an example for baseline houses solar water heating is taken an ac power circulator pump connected to the number of panels that give the least number of years for equity payback. The house size system in Victoria used the following data into the RETScreen with Excel program. In Tables 3 and 4 show the daily hot water use and temperatures for a house in Victoria were taken from RETScreen 2007 example data on an actual house [58].

This data is from evacuated solar water heater system. At the example house, required heating is taken from invoices. RETScreen climate database was used for the resource assessment or the available amount of sun available [54,58].

10.2. Water systems

15 pounds of water storage are needed on every square foot of collector or 1.8 gallons of storage is needed for each square foot of collector, because the water has a specific heat of Btu/1b-°F [75].

10.3. Air systems

The optimum storage size of rock is 0.8 ft per square foot of collector, since rock has a specific heat of 0.21 BUT/1b-°F and rock densities typically contain 20–40 percent voids. Storage volumes in this range store the equivalent overnight of the full day of heating. Fig. 8 shows the typical domestic hot water system. The use of two tanks ensures that when hot water from the first tank is available, the auxiliary heat does not come on, and also total fuel is used to bring the smeller second tank up to temperature. Because of the frequent activation of the heating element, every time there is a draw of water, rather than wait for additional heated water to be provided, therefore, the single tank arrangements are not recommended. As shown in Fig. 9, this control problem is avoided by two tank arrangement It. is suitable to retrofit two tank arrangements, since for the second tank the water heater is already there would be variation if a heat exchanger (copper coil) is used as in Fig. 10 in the tempering tank collector loop for freeze protection. Then tempering tank becomes an inexpensive unpressurized tank [61,65,72,75,76].

Table 3
Baseline house RETScreen data [58].

Load type	House
Number of units	3 Occupant
Occupancy rate	100%
Daily hot water use – estimated	180 L/d
Daily hot water use	180 L/d
Temperature	65 °C
Operating days per weeks	7 D

10.4. Storage tanks

Variety of containers usually made of steel, concrete, plastic, fiber glass or other suitable materials, are used to store hot water. From the all types of materials steel tanks are mostly available as commercial and have been used for water storage, and are easy to install and available in many sizes. To avoid corrosion steel tanks should be lined or galvanized because they susceptible to corrosion. Dissimilar metal at pipe connections should be separated by high temperature rudder connections or galvanic corrosion will occur. Proper insulation of steel tanks is necessary to avoid heat losses [75].

Fiber glass and plastic tanks are corrosion resistant and installed easily. Available of these tanks is in many shapes and size. Although many commonly fabricated tanks are sensitive to high temperatures above 140 °F, some especially fabricated tanks are available which can withstand temperatures up to 150 °F but are more

Table 4
Percent of month used of solar water heater [58].

Supply temperature method for collector	House
Water temperature minimum	7.4%
Water temperature maximum	11.9%
Slope	45°

expensive. The types of plastic tanks can be more expensive than steel. The tanks that are buried must be protected from resist buoyant forces and groundwater. When the repairs needed, the tank must be accessible. Outdoor location may be feasible if there are mild or warm climates outside.

10.5. Domestic hot water system

Pressurized or lined insulated tanks similar to the conventional water heater can be used in the domestic hot water systems without space heating. For safety purpose, suitable temperatures and pressure relief valves must be used. For the possibility for solar collectors to reach high temperatures, mixing or tempering valve should be used. With proper valves settings and connections, a typical two tank installation is shown in Fig. 8. For a typical family house, the hot water consumption rate is 20 gal/day/person. Average use is 30 gal/day/person while the hot water consumption rate is more. Therefore, for atypical four person family, 80–120 gal/day should be served. The overall thermal performance of the system since it enables the direct evaluation of the system, which will make available to the user [67].

11. Conclusion

The critical outcomes from this study are summarized below:

- The great efforts have been made by the researchers to develop solar water heaters. It has been carried out for constant hot water collection temperature, and it is also observed that the thermal and exergy efficiency has reversed trends with respect to collection temperature as expected.
- This type of thermal analysis is used for designing the solar water systems using flow rate and number of collector as design parameters.
- Present study has evaluated the thermal performance of the flat plate, Concentration and other collector's solar water heater with a mantle heat exchanger and theoretically has presented an energy equation, including a heat exchanger penalty factor.
- The mathematical formulation of the heat transfer in recycling double pass sheet and tube of solar water heaters with internal fins attached under various arrayed densities has been studied theoretically.
- The solar water heat energy produced and energy storage with auxiliary heat by the solar water heater is very important for calculating solar energy and saving fuel cost.
- For most part of the day, the solar water heater is having a higher temperature of water for use than the plane surface. The performance improves further with night insulation cover. Even though there is a decrease in the efficiency marginally in the solar water heater with the siphon system but that can be minimized by constant withdrawal of hot water from the tank.

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